Impact of Above Cloud Aerosol on the Angular Distribution Pattern of Cloud Bidirectional Reflectance and Implication for Above Cloud Aerosol Direct Radiative Effect

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1. Introduction and Theory
With passive remote sensing: the difficulties in calculating the direct radiative effect of above cloud aerosols \( \text{DRE}_{\text{true}} \) follow directly from the lack of information of the angular dependencies of the radiances fields due to above-cloud aerosols (ACA).

Where knowledge of angular distribution model (ADMs) for an unpolluted cloud (CC) scene can allow for reasonable estimation of scene irradiance from a single scene reflectance:

\[
F_{\text{CC}}^{\text{true}}(\lambda) = \mathcal{P}(\lambda) \cdot S(\lambda) \mu_{a} \rightarrow F_{\text{CC}}^{\text{true}}(\lambda) = \frac{\gamma_{\text{CC}}(\mu_{a}, \phi_{c}, \phi_{t})}{\alpha_{\text{CC}}(\mu_{a}, \phi_{c}, \phi_{t})} S(\lambda) \mu_{a},
\]

(where \( \gamma_{\text{a}} \) is the spectral BRDF and \( \alpha_{\text{a}} \) is the spectral Anisotropy factor) no analogous representation for the upwelling flux from a polluted (ACA+CC) scene exists.

An investigation of the differences between the CC and ACA+CC ADMs may be able to provide the necessary angular information that will allow for constrained approximations to \( \text{DRE}_{\text{true}} \) from sparse observations of the upwelling radiances field of an ACA+CC scene.

In lieu of such information, algorithms for spectral calculation of \( \text{DRE}_{\text{true}} \) have been developed that approximate the ADM due to an ACA+CC scene as simply the ADM due to a CC scene, i.e.:

\[
\text{DRE}_{\text{TRUE}} = \frac{\gamma_{\text{CC}}(\mu_{a}, \phi_{c}, \phi_{t})}{\alpha_{\text{CC}}(\mu_{a}, \phi_{c}, \phi_{t})} S(\lambda) \mu_{a}.
\]

The preliminary results of an investigation of the differences between this approximation and a ‘true’ spectral \( \text{DRE}_{\text{true}} \) algorithm will be shown here, with emphasis on the angular regions where the two methods agree. Such agreement will be seen to be an indicator of good agreement between the CC and ACA+CC ADMs, otherwise where incurred error becomes negligible when integrated spectrally.

2. Methods
i. Calculation of Bulk Scattering Properties (BSP) at bands selected for good representation of solar spectrum
ii. Compute spectral BRDF & A for CC scene
iii. Compute spectral BRDF & A for ACA+CC scene
iv. Calculate spectral DRE_{\text{true}} (True & Approximate)
v. Spectral integral over the solar spectrum yields \( \text{DRE}_{\text{true}} \)

3. Comparison of True and Approximated Algorithms

Above: Comparison plots of BRDF (left col.) and Anisotropy (right col.) along the principle plane. Dashed lines represent actual observation angles at which \( \text{DRE}_{\text{true}} \) is later calculated (see for right plot). Blue line and solid magenta line are the cases where \( \pm 15\% \) and \( \pm 50\% \) error is assumed in \( \text{DRE}_{\text{true}} \). Red line represents \( \text{DRE}_{\text{true}} \) in absence of a good baseline, note the relative values and their dependence on AOD. These influence the spectral error as shown above and in the results section.

Below: Comparison plots of \( \text{DRE}_{\text{true}} \) with both methods and their approximation (right col.) through increasing AOD (at anchor: 0.08, 0.33, 0.81, 0.83) in absence of a good baseline, note the relative values and their dependence on AOD. These influence the spectral error as shown above and in the results section.

4. Results

5. Outlook

Handled here is a study of the angular sensitivity of the error incurred via the approximation of ACA+CC ADMs as CC ADMs. For a more complete picture; an investigation of the sensitivity to assumed aerosol model must be completed.

Additionally, these results are from a 1-D PDA RT Code run on specific scenes with specific atmospheric pressure profiles. As smaller (visible) wavelengths, Rayleigh reflectances from pressure-thick layers will influence these results.

Above-Left: Pressure profiles used for these data
Above-Right: Sample pressure profile for future work (blue: Rayleigh Atmosphere, grey: aerosol, white: cloud)

Left: Sample joint probability distribution function for AOD and COD

Also, the regional effects of the aforementioned ADM approximations may be interesting, in which case, realistic spatial distributions of cloud and aerosol optical depth will be developed, the \( \text{DRE}_{\text{true}} \) calculated for each permutation, and then the entire ensemble weighted by the distribution.

\[
\text{DRE}_{\text{ACKNOWLEDGMENTS}} = \int \int \text{DRE}_{\text{ACKNOWLEDGMENTS}}(\tau_{\text{CC}}, \tau_{\text{ACA}}) \cdot p(\tau_{\text{CC}}) \cdot p(\tau_{\text{ACA}}) d\tau_{\text{CC}} d\tau_{\text{ACA}}
\]

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